Appendix B
(Copy of Certified Priority Document)

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2. Patent application number *(The Patent Office will fill in this part)* — 0323673.4

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — QINETIQ LIMITED

   Registered Office 85 Buckingham Gate
   London SW1E 6PD
   United Kingdom

   Patents ADP number *(if you know it)* — 8183857001

   If the applicant is a corporate body, give the country/state of its incorporation — GB

4. Title of the invention — Improvements in and relating to perforators

5. Name of your agent *(if you have one)* — Ian Michael Johnson

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Description 7

Claim(s) 2

Abstract 1

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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*

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11. I / We request the grant of a patent on the basis of this application.

Signature I.M. Johnson, Agent for the Applicant Date: 10 October 2003

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(Superseded copy)

Improvements in and relating to Perforators

The present invention relates to a gun or carrier for perforator charges used in perforating and fracturing well completions particularly, although not exclusively, oil, gas, water and steam wells.

By far the most significant process in carrying out a completion in a cased well is that of providing a flow path between the production zone, also known as a formation, and the well bore. Typically, the creation of such a flow path is carried out using a perforator, with the resulting aperture in the casing and physical penetration into the formation via a cementing layer being commonly referred to as a perforation. Although mechanical perforating devices are known, almost overwhelmingly such perforations are formed using energetic materials e.g. high explosives. Energetic materials can also confer additional benefits in that may provide stimulation to the well in the sense that the shockwave passing into the formation can enhance the effectiveness of the perforation and produce increased flow from the formation. Typically, such a perforator will take the form of a shaped-charge. In the following, any reference to a perforator, unless otherwise qualified, should be taken to mean a shaped charge perforator.

A shaped charge is an energetic device made up of an axisymmetric case within which is inserted a liner. The liner provides one internal surface of a void, the remaining surfaces of the void being provided by the enclosure. The void is filled with a high explosive such as HMX, RDX, PYX or HNS which, when detonated, causes the liner material to collapse and be ejected from the casing in the form of a high velocity jet of material. It is this jet of material which impacts upon the well casing creating an aperture and then penetrates into the formation itself. Generally, a large number of perforations are required in a particular region of the casing proximate a formation. To this end, a so called gun is deployed into the casing by wireline, coiled tubing or indeed any other technique know to those skilled in the art. The gun is effectively a carrier for a plurality of perforators which may be of the same or differing output. The precise type of perforator, their number and the size of the gun are a matter generally decided upon by a completion engineer based on an analysis and/or assessment of the characteristics of the completion. Depending on the nature of the formation, the aim of the completion engineer may be either to obtain the largest possible aperture in the casing or to obtain the deepest possible penetration into the surrounding formation. Thus, in an unconsolidated formation, the former will be preferred whereas in a consolidated formation the latter will be desired. It

will be appreciated that the nature of a formation may vary both from completion to completion and also within the extent of a particular completion.

Typically, the actual selection of the perforator charges, their number and arrangement within a gun and indeed the type of gun is left to the completion engineer. A particular constraint on the engineer and his selection of the charges is the carrier or gun used to convey the charges into the well. The carrier is a containment device which seeks to contain the explosive force to an extent necessary to protect the well casing from the effects of fragmentation. The carrier further acts as a barrier between the pressurised fluids in the well and the perforator charges. Almost universally, steel is used as the material of choice in the manufacture of carriers. Consequently, a carrier is heavy and difficult to handle.

The completion engineer will base his decision on an empirical approach born of experience and knowledge of the particular formation in which the completion is taking place. However, to assist the engineer in his selection there have been developed a range of tests and procedures for the characterisation of perforator performance. These tests and procedures have been developed by the industry via the American Petroleum Institute (API). In this regard, the API standard RP 19B (formerly RP 43 5th Edition) currently available for download from www.api.org is used widely by the perforator community as indication of perforator performance. Manufacturers of perforators typically utilise this API standard marketing their products. The completion engineer is therefore able to select between products of different manufacturers for a perforator having the performance he believes is required for the particular job in hand. In making his selection, the engineer can be confident of the type of performance to expect from the perforator.

Nevertheless, despite the existence of these tests and procedures there is recognition that completion engineering remains at heart more art than science. It has been recognised by the inventors in respect of the invention set out herein, that the conservative nature of the current approach to completion has failed to bring about the change in the approach to completion engineering required to enhance and increase production from both straightforward and complex completions.

Thus, in accordance with a first aspect of the invention, there is provided a carrier for at least one shaped charge, the carrier being disposable, in use, within a well bore, the carrier comprising a metallic housing being at least partially encompassed by a composite material overwrap and having at least one port formed therein.

Preferably, the metallic housing takes the form of a thin walled metal cylinder. Typically, a high strength steel will be employed. Advantageously, the metal cylinder will be of a thickness less than that employed in conventional carriers fabricated entirely of metal. Such a reduction in thickness can bring about a reduction brings about a weight saving.

The provision of a composite material overwrap enhances the performance of the carrier. Conveniently, the physical characteristics of the composite material, by which is meant the particular selection of material and/or the structure of the composite material can be selected to match the requirements for the carrier. In particular, it is expected that axial and hoop properties of the overwrap composite material may be tuned independently to deal with the distribution in stresses occurring both during handling of the carrier and, of course, on detonation of the one or more perforators. Advantageously, the axial flexibility of the carrier may be tuned to facilitate easier transport of the carrier both into the well and through deviations therein. Preferably, the fibre tension of the composite material can be tuned to maximise containment of the explosive energy dissipated during firing of the one or more perforators to reduce the level of dilation. The firing or initiation of a perforator brings about a localised pressurisation/impulse which results in an expansion or dilation of the carrier. Excessive dilation of the carrier may result in the carrier becoming lodged within the well casing with obvious negative consequences. Consequently, the larger and/or more numerous charges may be utilised in a carrier than hitherto available in a convention carrier of equivalent dimensions.

In accordance with a further aspect of the invention, there is provided a carrier for at least one shaped charge, the carrier being disposable, in use, within a well bore, the carrier comprising a composite material housing having least one at port formed therein.

Whilst some of the advantages of utilising composite material in the fabrication of a carrier have already been indicated, there are further particular benefits arising from utilising composite material to fabricate substantially an entire carrier. Conveniently, as a result of the pressurisation/impulse being generated by firing of the perforators, the

composite material may selected and fabricated with a view to the carrier fragmenting into debris of insufficient size and therefore energy to cause appreciable damage to surrounding structure including the formation. The selection of the composite material can be such that this fragmentation occurs only in the event of a pressurisation/impulse outside of the expected limits for the carrier or completion. Alternatively, the carrier may be designed to fragment following a normal firing of the perforators. In this later case, the carrier may be referred to a one-shot carrier (or gun) and may further incorporate perforators which themselves are intended to break up into fragments on detonation which fragments themselves are intended not to cause appreciable damage to surrounding structures or well equipment such as valves.

In order to assist in understanding the invention, a number of embodiments thereof will now be described, by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a sectional view of a completion in which a gun or carrier according to an embodiment of the invention is shown;
Figure 2 is a scrap sectional side view of the gun or carrier according to a first aspect of the invention;
Figure 3 is a cross-sectional view on the line III-III of Figure 2 of the carrier of Figure 2;
Figure 4 is a scrap sectional side view of the gun or carrier of a further aspect of the invention.

In the following, references to a carrier or gun are intended to be interchangeable.

With reference to Figure 1, there is shown a stage in the completion of a well 1 in which, the well bore 3 has been drilled into a pair of producing zones 5,7 in, respectively, unconsolidated and consolidated formations. A steel tubular or casing of steel is cemented within the bore 3 and in order to provide a flow path from the production zones 5,7 into the eventual annulus that will be formed between the casing 9 and production tubing (not shown) which will be present within the completed well, it is necessary to perforate the casing 9. In order to form perforations in the casing 9, a gun 11 is lowered into the casing on a wireline, slickline or coiled tubing 13, as appropriate.

As is shown in more detail in Figures 2 and 3, the gun 11 comprises an inner cylindrical tube 14 of steel in which are formed ports 15 through which perforator charges 17 received within the body of the gun 11 are fired. Encompassing the inner cylindrical tube 14 is an overwrap of composite material 16. The overwrap 16 effectively forms an outer cylindrical tube in which ports 15 are provided to correspond with those formed in the inner cylindrical tube 14.

The overall diameter of the gun 11 is selected to be a close but not interference fit with the casing 9 as shown in Figure 1. Thus, the gun 11 is effectively self-centring within the casing 9. By having the gun self-centred within the casing 9, there is little or minimal variation in the standoff distance between the charges 17 and the casing 9. Any significant variation in the standoff distance may have a detrimental effect on the consistency of performance of the perforators 17.

In use, the gun 11 is lowered into the well 1 to a depth where it is adjacent the production zone 5,7. It may be that the extent of the production zone 5,7 exceeds the length of a gun 1 in which case a string of guns may be lowered and/or a number of operations may be required to fully perforate the casing in the region of the zone. Furthermore, it may be that where the formation is relative unconsolidated, the perforators 17 may be intended to provide a larger aperture in the casing 9 at the expense of depth of penetration into the formation. Conversely, a small aperture may be formed in the casing 9 where a greater depth penetration is required, such as, for example, in highly consolidated sediment. In either case, the completion engineer will attempt to select the most appropriate charges for the particular perforations required in the casing 9.

Turning to Figure 4, there is shown a further embodiment in which the entire gun 11' is formed as a thin walled cylinder of composite material 16'. The cylinder is formed with ports 15' and suitable attachment points within the body of the cylinder for receiving perforator charge 17'.

The composite material used either as an overwrap for a steel cylinder 14 or in fabricating an entire gun 11 is selected to add additional strength amongst other improvements to the physical performance of the gun. Thus, a composite material may be formed from a reinforced polymeric material. Some non-limiting examples of

reinforcement include providing reinforcement by a preform or in a variant of the embodiment using individual rovings.

The preform may be fabricated by hand lay up, filament winding, compression moulding or braiding using a binder to maintain the desired profile, to give just four examples. A matrix into which a solid material loading is added, can include one or more plastics material. The plastics material will be selected from types including, but not limited to one or more of the following, namely thermosets, thermoplastics and elastomers, It will be appreciated that the selection of a plastics material is, to a great part, made on the basis of its performance at the temperatures likely to obtain with a completion. In some circumstances, a gun 11 may remain within a casing 9 for extended periods before it is used. Thus the plastics material may need to be selected to withstand not only raised temperature, perhaps 200°C but to maintain performance at elevated temperature for a significant period of days or even weeks.

It has been determined that of the class of thermoplastics, materials such as polystyrene, polymers of olefins containing 2 to 10 carbon atoms such as polyethylene and polypropylene are suitable for selection up to temperatures of around 200°C. Around and above this temperature, plastics material having higher meting points such as polyethersulfone (PES), polyoxymethylene (POM) and PK for example, can be utilised.

Into the matrix described above may be added a filler material. The filler material may include one or more preferably metallic materials. For example, a metallic material may be selected from the following non-exclusive list, namely copper, aluminium, iron, tungsten and alloys thereof. Additionally or alternatively, a non-metallic material or materials may be selected. Such materials include, but are not limited to inorganic or organic materials such as borides, carbides, oxides, nitrides of metals and glasses, especially refractory metals.

As has been noted previously, it has been found that fragmentation of prior art guns brought about by the explosive effect of one or more perforators 17 can cause collateral damage to the structures surrounding the gun including the formation 5,7. Fragments of such a prior art gun can be carried by well fluids into valves and such like where they can lodge and/or initiate corrosion, particularly where zinc is used in the manufacture of the gun. It is therefore proposed that in a variant of the second described embodiment, the

composite material is selected with a view to the gun fragmenting into debris of insufficient size and therefore energy to cause appreciable damage to surrounding structure or indeed well equipment in the event of an excess of energy being released by detonation of the perforators. The selection of a friable composite material can be such that this fragmentation occurs only in the event of an overloading of the gun or as a deliberate result of the firing of the perforators. In the later case, the gun may be referred to as a one-shot gun and may further incorporate perforators which themselves are intended to form fragments on detonation which do not cause appreciable damage to surrounding structures.

It will be appreciated by those skilled in the art that a manufacturing method suitable for the composite material elements of the embodiments of the gun described above, could be selected from the following non-exclusive list. Thus, a matrix utilising a particulate reinforcement is formed by preparing a mixture of these two components and compounding them under vacuum. A gun or overwrap of compounded thermoplastic and particulate materials can be formed using injection or compression moulding. Injection moulding is believed to be particularly suitable for a gun using a dry preform. Compression moulding may be effective for a gun or overwrap having a preform containing thermoplastic fibres co-mingled with the reinforcement.

Where a gun or carrier is to be formed by filament winding, it is suggested that this might provide excellent strength and dimensional accuracy.

Claims

1. A carrier for at least one shaped charge, the carrier being disposable, in use, within a well bore, the carrier comprising a metallic housing being at least partially encompassed by a composite material overwrap and having at least one port formed therein.

2. A carrier as claimed in Claim 1, wherein the housing is a thin-walled metal cylinder.

3. A carrier as claimed in Claim 1 or Claim 2, wherein a plurality of ports are distributed along the longitudinal extent of the carrier.

4. A carrier for at least one shaped charge, the carrier being disposable, in use, within a well bore, the carrier comprising a composite material housing having least one at port formed therein.

5. A carrier as claimed in Claim 4, wherein the housing is a thin-walled cylinder.

6. A carrier as claimed in Claim 4 or Claim 5, wherein a plurality of ports are distributed along the longitudinal extent of the carrier.

7. A carrier as claimed in any one of Claims 1 to 3 or Claims 4 to 6, wherein the composite material is friable.

8. A carrier as claimed in any preceding Claim, wherein the composite material is a loaded polymer matrix.

9. A carrier as claimed in any preceding Claim, wherein the composite material includes circumferentially arranged fibres.

10. A carrier as claimed in any preceding Claim, wherein the composite material includes longitudinally arranged fibres.

11. A carrier as claimed in Claim 10 as appendant to Claim 9, wherein said circumferentially arranged fibres have respective predetermined tensions.

Abstract

Improvements in and relating to Perforators

A composite material overwrap 16 is utilised to strengthen a steel inner cylinder 14. The resulting structure provides a carrier 11 for perforators 17 used in completion operations. In a further embodiment, the entire carrier $11'$ is fabricated from a composite material $16'$.

Fig. 2

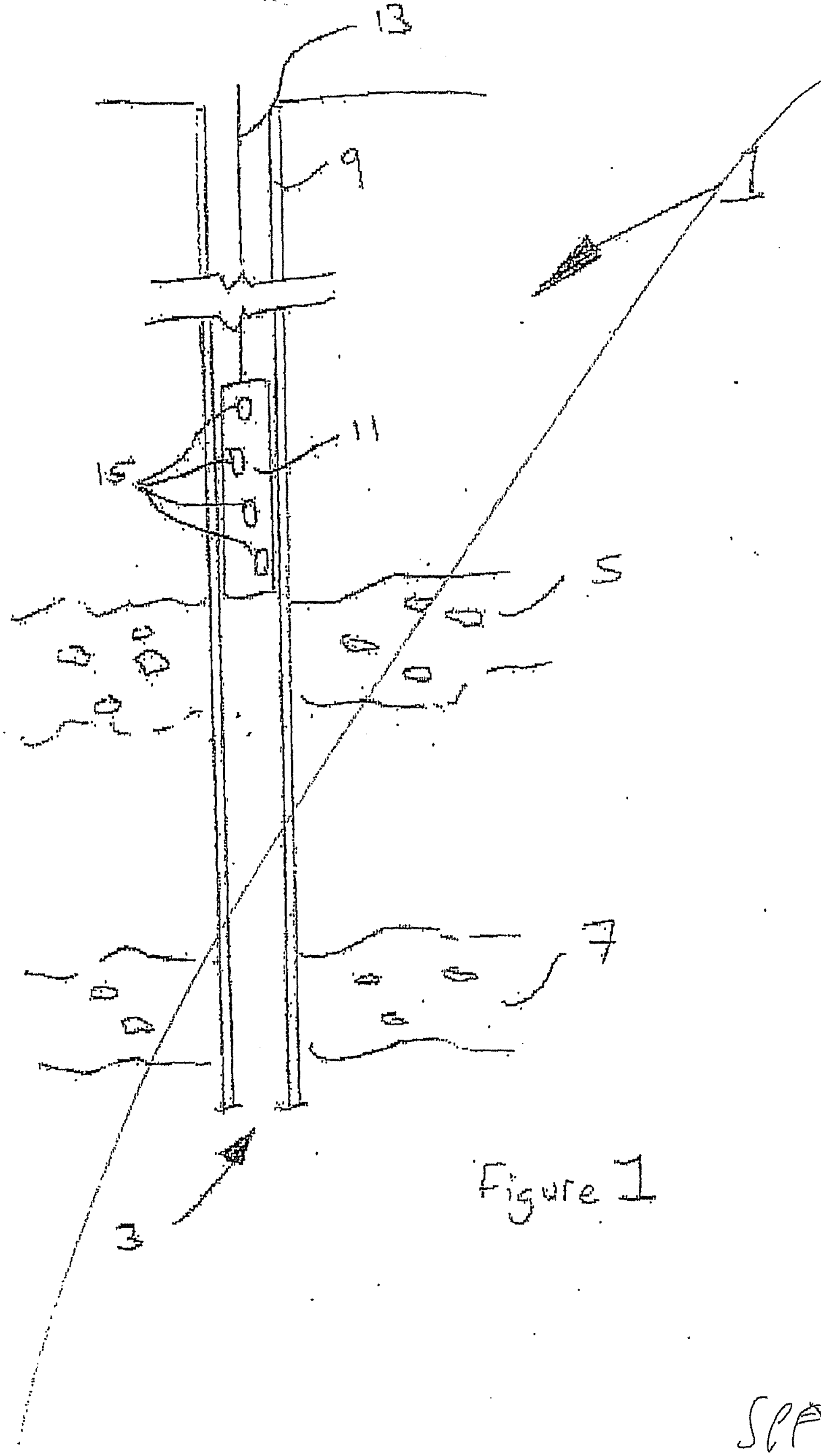

Figure 1

SPARE

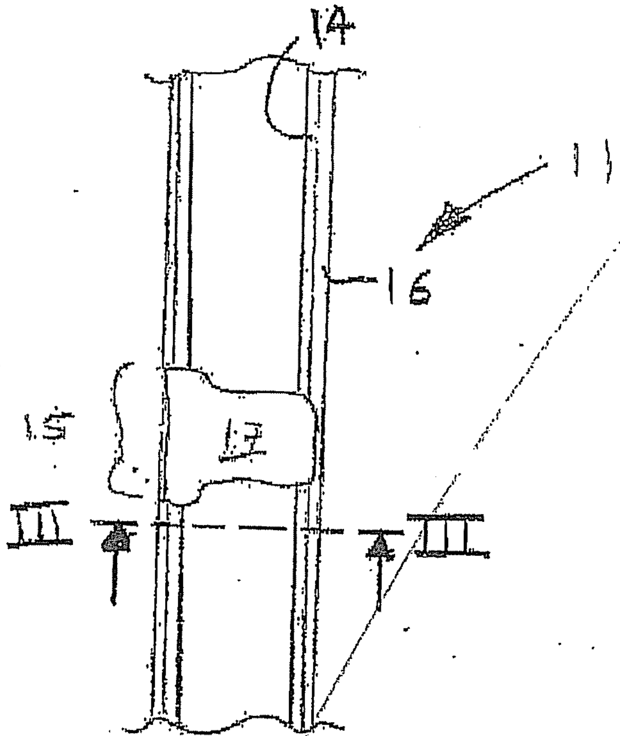

Figure 2

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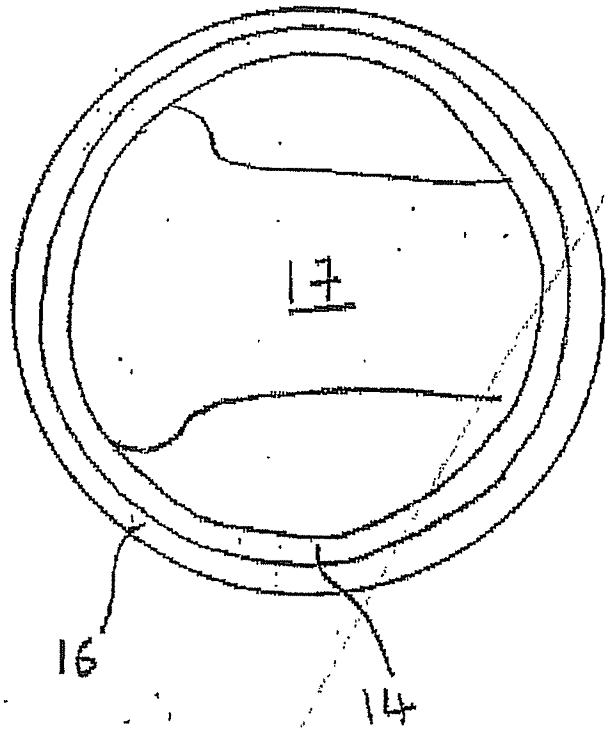

Figure 3

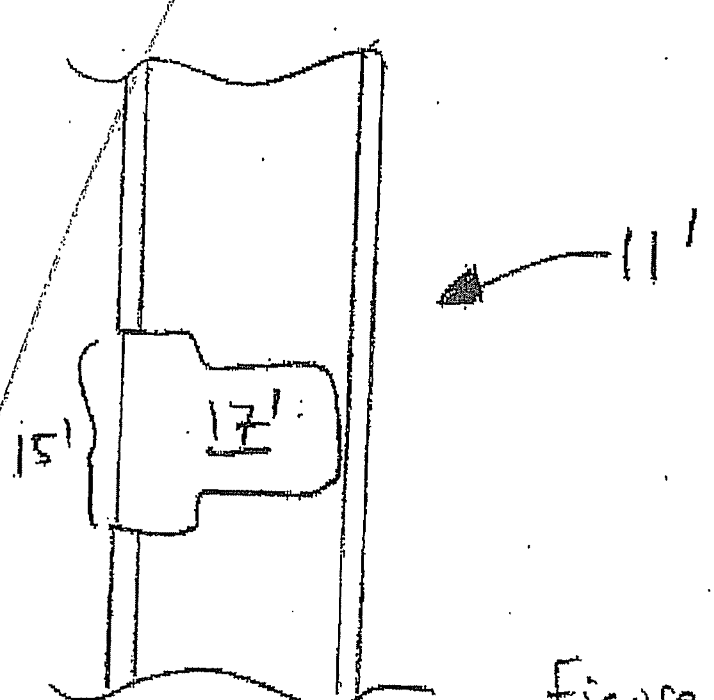

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Figure 4